

CLAIMS

We claim:

1 1. A variable speed wind turbine system comprising:
2 a wound rotor induction generator;
3 a torque controller coupled to the generator to control
4 generator torque using field oriented control; and
5 a pitch controller coupled to the generator to perform pitch
6 regulation based on generator rotor speed and operating
7 independently of the torque controller.

1 2. The system defined in Claim 1 wherein the pitch
2 controller comprises a proportional, integral derivative (PID)
3 pitch controller.

1 3. The system defined in Claim 1 wherein the pitch
2 controller comprises a proportional, integral (PI) pitch controller.

1 4. The system defined in Claim 1 wherein the pitch
2 controller comprises a proportional, derivative (PD) pitch
3 controller.

1 5. The system defined in Claim 1 wherein the pitch
2 controller comprises a Lag-Lead controller.

1 6. The system defined in Claim 1 wherein the pitch
2 controller comprises a Lead-Lag controller.

1 7. The system defined in Claim 1 where the pitch
2 controller comprises an open loop controller with a derivative
3 term.

1 8. The system defined in Claim 1 wherein the wound
2 rotor induction generator comprises a non-slip ring induction
3 generator.

1 9. The system defined in Claim 1 wherein the torque
2 controller comprises a dampening filter to reduce commanded
3 torque based on detected oscillation motion between turbine
4 blades and the generator.

1 10. A variable speed system comprising:
2 a wound rotor induction generation means for generating
3 power;

4 a torque controlling means for controlling generator torque
5 using field oriented control; and
6 a pitch controlling means for performing pitch regulation
7 based on generator rotor speed and operating independently of
8 the torque controller.

1 11. The system defined in Claim 10 wherein the pitch
2 controlling means comprises a proportional, integral derivative
3 (PID) pitch controller.

1 12. A variable speed wind turbine system comprising:
2 a wound rotor induction generator;
3 a torque controller coupled to the generator to control
4 generator torque using field oriented control; and
5 a proportional, integral derivative (PID) pitch controller
6 coupled to the generator to perform pitch regulation based on
7 generator rotor speed.

1 13. The system defined in Claim 12 wherein the wound
2 rotor induction generator comprises a non-slip ring induction
3 generator.

1 14. The system defined in Claim 12 wherein the power
2 controller controls the generator power and torque as a function
3 of generator speed.

1 15. The system defined in Claim 12 wherein the power
2 controller controls the generator power from a power look up
3 table (LUT) as a function of generator speed using field oriented
4 control (FOC).

1 16. The system defined in Claim 12 wherein the power
2 controller comprises a look up table (LUT) of power and
3 corresponding generator rotor speeds, and wherein the power
4 controller interpolates the LUT using a measured generator rotor
5 speed to determine a target output power, from which the torque
6 controller determines a desired generator torque using the
7 measured generator rotor speed. ,

1 17. The system defined in Claim 16 wherein the power
2 controller causes the generator to follow a predetermined power-
3 speed curve encoded in the LUT.

1 18. The system defined in Claim 12 wherein the power
2 controller comprises:

3 a LUT encoding a predetermined power-speed curve,
4 wherein the LUT outputs a target output power in response to a
5 measured generator rotor speed;
6 a comparator to generate a power error indication based on
7 a comparison of actual output power to the target output power;
8 a proportional, integral (PI) controller coupled to the power
9 error indication to generate an adjusted actual output power in
10 response to the calculated power error indication; and
11 a divider to generate a commanded torque in response to
12 the measured generator rotor speed and the adjusted actual
13 output power.

1 19. The system defined in Claim 18 further comprising a
2 feedforward dampening term filter coupled to change the
3 commanded torque in response to the measured generator rotor
4 speed.

1 20. The system defined in Claim 12 wherein the power
2 controller controls generator torque by commanding a required
3 rotor current vector which interacts with an identified flux vector
4 to produce a desired generator torque.

1 21. The system defined in Claim 12 wherein the power
2 controller controls torque at least from cut-in to rated wind
3 speeds.

1 22. The system defined in Claim 12 wherein the power
2 controller controls torque from cut-in to rated wind speeds.

1 23. The system defined in Claim 12 wherein the power
2 controller causes the generator to follow a predetermined power-
3 speed curve.

1 24. The system defined in Claim 12 wherein the power
2 controller commands a preselected constant torque to slow the
3 wound rotor.

1 25. The system defined in Claim 24 wherein the
2 preselected constant torque comprises a maximum preselected
3 constant torque.

1 26. The system defined in Claim 12 further comprising a
2 generator speed indication coupled to inputs of the power
3 controller and the PID controller.

1 27. The system defined in Claim 12 wherein the power
2 controller operates independently of the PID pitch controller.

1 28. The system defined in Claim 12 wherein the PID
2 pitch controller comprises a closed loop PID controller with pitch
3 angle being fed back.

1 29. The system defined in Claim 12 wherein the PID
2 pitch controller comprises an open loop controller with a
3 derivative term.

1 30. The system defined in Claim 12 wherein the PID
2 pitch controller generates a pitch velocity to perform pitch
3 regulation.

1 31. The system defined in Claim 12 further comprises a
2 wind turbine having at least one blade coupled to the generator,
3 and wherein the PID pitch controller controls generator rotor
4 speed by pitching said at least one blade.

1 32. The system defined in Claim 31 wherein the PID
2 pitch controller pitches said at least one blade based on a

3 difference in actual generator rotor speed and commanded
4 generator rotor speed.

1 33. The system defined in Claim 12 further comprising:
2 a comparator to generate speed error indication based on a
3 comparison between a measured generator rotor speed and a
4 target generator rotor speed, and wherein the PID pitch controller
5 generates an output pitch velocity value in response to the speed
6 error indication; and
7 a non-linear LUT coupled to output a command voltage to
8 drive a proportional valve to effect pitching action in response to
9 the pitch velocity value.

1 34. A variable speed wind turbine having a plurality of
2 blades comprising:
3 a doubly-fed generator having a wound rotor;
4 a power converter coupled to the wound rotor of the
5 doubly-fed generator and having a LUT containing an encoded
6 power-speed curve, wherein the power converter samples
7 generator rotor speed, updates a desired output power from the
8 LUT using the generator rotor speed, determines a new torque
9 based on an updated desired output power, and calculates a new
10 current vector that is impressed upon the wound rotor; and

11 a closed loop proportional, integral derivative (PID) pitch
12 controller coupled to pitch the plurality of blades based on
13 generator rotor speed.

1 35. The turbine defined in Claim 34 wherein the power
2 converter and PID pitch controller operate independently.

1 36. The turbine defined in Claim 34 wherein the power
2 converter holds power constant above rated wind speeds.

1 37. The turbine defined in Claim 36 wherein the power
2 converter holds power constant by controlling rotor current to
3 provide the proper torque.

1 38. The turbine defined in Claim 34 wherein the PID
2 pitch controller generates a pitch velocity to perform pitch
3 regulation.

1 39. The turbine defined in Claim 34 wherein the PID
2 pitch controller pitches the plurality of blades based on a
3 difference in actual generator rotor speed and commanded
4 generator rotor speed.

1 40. The turbine defined in Claim 34 further comprising:
2 a comparator to generate a speed error indication based on a
3 comparison between a measure generator rotor speed and a target
4 generator rotor speed, and wherein the PID pitch controller
5 generates a pitch velocity command in response to the speed error
6 indication; and
7 a non-linear LUT coupled to output a drive voltage to be
8 applied to a proportional value to accomplish blade pitch motion
9 in response to the pitch velocity command.

1 41. A variable speed wind turbine having a plurality of
2 blades comprising:
3 a doubly-fed generation means for generating power,
4 wherein the generation means has a wound rotor;
5 a power converting means for transforming alternating
6 current to direct current, wherein, the power converting means
7 has a LUT containing an encoded power-speed curve, wherein the
8 power converting means includes means for sampling generator
9 rotor speed, means for updating a desired output power from the
10 LUT using the generator rotor speed, means for determining a
11 new torque based on an updated desired output power, and
12 means for calculating a new current vector that is impressed upon
13 the wound rotor; and

14 a closed loop proportional, integral derivative (PID) pitch
15 controlling means for pitching the plurality of blades based on
16 generator rotor speed.

1 42. The turbine defined in Claim 41 wherein the power
2 converting means and PID pitch controlling means operate
3 independently.

1 43. The turbine defined in Claim 41 wherein the power
2 converting means includes means for holding power constant
3 above rated wind speeds.

1 44. The turbine defined in Claim 43 wherein the power
2 converting means includes means for holding power constant by
3 controlling rotor current to provide the proper torque.
4

1 45. A method of controlling generator power
2 comprising the steps of:
3 measuring generator rotor speed;
4 accessing a LUT using measured rotor speed to obtain a
5 target output power;

6 comparing actual output power and the target output
7 power;
8 generating a commanded torque by adjusting a torque
9 calculation to maintain a predetermined output based on
10 comparison of actual output power to the target output power.

1 46. The method defined in Claim 45 wherein the
2 commanded torque comprises a predetermined constant torque to
3 slow down the generator rotor speed.

1 47. The method defined in Claim 45 wherein the
2 predetermined constant torque comprises a maximum constant
3 torque.

1 48. An apparatus for controlling generator power
2 comprising the steps of:
3 means for measuring generator rotor speed;
4 means for accessing a LUT using measured rotor speed to
5 obtain a target output power;
6 means for comparing actual output power and the target
7 output power;

8 means for generating a commanded torque by adjusting a
9 torque calculation to maintain a predetermined output based on
10 comparison of actual output power to the target output power.

1 49. A method of controlling generator torque of a
2 variable speed system, said method comprising the steps of:
3 identifying a stator flux vector;
4 commanding a rotor current vector; and
5 producing a desired generator torque by interacting the
6 stator flux vector and the rotor current vector.

1 50. A synchronization process for a variable speed
2 system having a generator, said process comprising the steps of:
3 connecting a generator stator;
4 connecting a generator rotor;
5 ramping up a rotor current; and
6 regulating generator torque.

1 51. The process defined in Claim 50 wherein the step of
2 connecting the generator stator occurs at a first generator speed.

1 52. The process defined in Claim 51 wherein the step of
2 connecting the generator rotor occurs at a second generator speed

3 higher than the first generator speed and when rotor voltage is at
4 a first voltage.

1 53. The process defined in Claim 52 wherein the step; of
2 regulating generator torque comprises the steps of enabling a rotor
3 side converter and gating rotor side IGBTs.

1 54. The process defined in Claim 52 wherein the step of
2 regulating generator torque comprising the step of creating a
3 current vector that is able to produce the desired torque.

1 55. A variable speed wind turbine system having
2 turbine blades, the system comprising:
3 a wound rotor induction generator;
4 a torque controller coupled to the generator to control
5 generator torque, wherein the torque controller comprises a
6 dampening filter to reduce commanded torque based on detected
7 oscillation motion between the turbine blades and the generator;
8 and
9 a pitch controller coupled to the generator to perform pitch
10 regulation based on generator rotor speed and operating
11 independently of the torque controller.

- 1 56. The system defined in Claim 55 wherein the
- 2 dampening filter comprises a bandpass filter with a passband
- 3 centered at the resonant frequency of the generator and turbine
- 4 blades and a shaft coupling the generator and turbine blades
- 5 together.